# Power System Stability Enhancement by Simultaneous AC-DC Power Transmission

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

*Bachelor of Technology* in
Electrical Engineering

By

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Under supervision of

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2012

National Institute of Technology, Rourkela

# CERTIFICATE

This is to certify that the thesis entitled **"Power System Stability Enhancement by Simultaneous AC-DC Power Transmission"** submitted by **Abhijeet Haldar (108EE017)** and **Vishwarath Bhadauria (108EE039)** in the partial fulfillment of the requirement for the degree of **Bachelor of Technology** in **Electrical Engineering**, National Institute of Technology, Rourkela, is an authentic work carried out by them under my supervision.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

Date:

Rourkela

Prof. P. C. Panda

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We would also like to extend our gratitude to our friends and senior students of this department who have always encouraged and supported us in doing our work. We would like to thank all the staff members of Department of Electrical Engineering who have been very cooperative with us.

Last, but not least, we would like to thank the authors of various research articles and book that we referred to during the course of the project.

**Abhijeet Haldar (108EE017)**

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## ABSTRACT

It is difficult to load long extra high voltage (EHV) ac lines to their thermal limits as a sufficient margin is kept against transient instability. With the model proposed in this thesis, it will be possible to load these lines close to their thermal limits. The transmission lines are allowed to carry usual ac along with dc superimposed on it.

The added dc power flow does not cause any instability. This thesis gives us the feasibility of converting a double circuit ac line into composite ac–dc power transmission line to get the advantages of parallel ac–dc transmission in order to improve stability and dampen out oscillations.

The advantage of parallel ac-dc transmission for improvement of transient stability and dynamic stability and dampout oscillations has been established. Simulation has been carried out in MATLAB software package (Simulink Model). The results show the stability of power system both for natural response and response under faulty conditions.

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## Simulink Models:



## Results:

# CHAPTER 1

# INTRODUCTION

## I. INTRODUCTION:

In recent years, environmental, right-of-way (Row), and economic concerns have delayed the construction of a new transmission line. The demand of electric power has shown steady growth but geographically it is quite uneven. The power is often not available at the growing load centers but at remote locations. Often the regulatory policies, environmental acceptability, and the economic concerns involving the availability of energy are the factors determining these locations. Now due to stability considerations, the transmission of the available energy through the existing ac lines has an upper limit. Thus, it is difficult to load long extra high voltage (EHV) ac lines to their thermal limits as a sufficient margin is kept against transient instability.

The present situation demands for the fact that there is full utilization of available energy applying the new concepts to the traditional power transmission theory keeping in view the system availability and security. The flexible ac transmission system (FACTS) concepts is based on the application of power electronic technology to the existing ac transmission system, this improves stability to achieve power transmission close to its thermal limit.

Simultaneous ac–dc power transmission was earlier proposed through a single circuit ac transmission line i.e. uni-polar dc link with ground as return path was used. The limitations of ground as return path is due to the fact that the use of ground may corrode any metallic material if it comes in its path. The instantaneous value of each conductor voltage with respect to ground becomes higher due to addition of dc voltage, hence more discs have to be added in each insulator string so that it can withstand this increased voltage. The conductor separation distance was kept constant, as the line-to-line voltage remains unchanged. This thesis gives us the feasibility of converting a double circuit ac line into composite ac–dc power transmission line without altering the original line conductors, insulator strings and tower structures.

# CHAPTER 2

# BACKGROUND AND LITERATURE SURVEY

## II. BACKGROUND AND LITERATURE SURVEY:-

The flexible ac transmission system (FACTS) concepts is based on the application of power electronic technology to the existing ac transmission system, this improves stability to achieve power transmission close to its thermal limit.

Another way to achieve the same goal is by the application of simultaneous ac–dc power transmission to the traditional power system in which the transmission lines carry superimposed dc current along with ac current. Addition of the dc power does not cause any instability and both ac and dc power flows independently.

Earlier it was proposed through a single circuit ac transmission line i.e. uni-polar dc link with ground as return path was used. The limitations of ground as return path is due to the fact that the use of ground may corrode any metallic material if it comes in its path. The instantaneous value of each conductor voltage with respect to ground becomes higher due to addition of dc voltage, hence more discs have to be added in each insulator string so that it can withstand this increased voltage. The conductor separation distance was kept constant, as the line-to-line voltage remains unchanged.

This thesis gives us the feasibility of converting a double circuit ac line into composite ac–dc power transmission line without altering the original line conductors, insulator strings and tower structures.

Our approach is based on the fact that the power transfer enhancement is achieved without any alteration in the existing Extra High Voltage ac line. The objective is to utilize the advantage of parallel ac–dc transmission by loading the line close to its upper thermal limit.

## 2.1. Existing Transmission Issues and Solution

### 2.1.1. High Voltage DC Transmission:

#### *2.1.1.1. Introduction:-*

The history of electricity takes us to the first commercial electricity generated (by Thomas Alva Edison) in which direct current (DC) was used for electrical power. The very first transmission systems were also direct current systems. The drawback mainly included the fact that DC power at low voltage was difficult to be transmitted over long distances, hence giving rise to extra high voltage (EHV lines) carrying alternating current. With the development of high voltage rating valves, it was possible to transmit DC power at very high voltages over long distances, known as the HVDC transmission systems. HVDC transmission system was first installed in the year 1954 , (100kV, 20MW DC link) between Swedish mainland and the island of Gotland, since then a huge amount of HVDC transmission systems have been installed.

In the recent years concerning major issues such as environmental factors and control, HVDC transmission systems have become desirable for the following reasons:

1. Environmental benifts

2. It is more economical (cheapest solution)

3. Asynchronous ties are feasible

4. Control on the power flow

5. Sublime benefits to the transmission including stability, power quality etc.

#### *2.1.1.2. Problems associated with HVDC:-*

(a) Cost of converters:

The cost of installation at the Converter Stations is quite high, required at each end of a D.C. transmission link, whereas in an A.C. link only transformer stations are required.

(b) Reactive power requirement:

Both in rectification and in inversion reactive power is required.

(c) Generation of harmonics:

The higher order harmonics are present due to the presence of Converters in the D.C. link which can be removed by the use of filters.

(d) Difficulty of circuit breaking:

In the case of D.C. natural zero crossing is not present, hence DC circuit breaking is difficult.

(e) High power generation difficult:

Due to the problems associated with commutation in D.C. machines, voltage and speed are limited. Comparitively, lower power can be generated with D.C.

(f) Absence of overload capacity:

Converters cannot be overload as in transformers.

### 2.1.2. High Voltage AC Transmission

#### *2.1.2.1. Introduction:-*

The industrial growth mainly depends on the energy availability and requires energy particularly electrical energy for its development. The source of power that mainly includes the natural resources have been depleted to a large extent and thus sources of energy other than Hydro and Thermal are required to meet the demand for the rapid rate of consumption. The increasing demand has led to the increase in generation and transmission facilities. Thus high voltages are required for transmission. Thus steps were taken by the development of dc transmission, since 1950 it has playing a major role in extra-long-distance transmission.

#### *2.1.2.2. Problems associated with HVAC:-*

(*a*) The Current Density increases due to the increase in line loading by series capacitors.

(*b*) Higher surface voltage gradient on conductors hence skin effect.

(*c*) Corona problems: Audible Noise, Radio Interference, Corona Energy Loss, and TV Interference.

(*d*) Electrostatic field under the line is high.

(*e*) Switching Surge Over voltage causes more difficulty in insulation than lightning and power frequency voltages.

(*f*) Increased Short-Circuit currents.

## 2.2. Theory of Simultaneous AC-DC Transmission:

Fig. 1 depicts the basic model for simultaneous ac-dc power flow through a dual circuit ac transmission line. Line commutated 12-pulse rectifier bridge is used in conventional HVDC and the dc power is injected to the neutral point of the zig-zag connected secondary of sending end transformer and is recovered back to ac again by the line commutated 12-pulse bridge inverter at the receiving end side. The inverter bridge is also connected to the neutral of zig-zag connected winding of the receiving end transformer to recover back the dc current to the inverter.

The dual circuit ac transmission line carriers both three-phase ac and dc power. Each conductor of each transmission line carries one third of the total dc current with ac current superimposed. Since the resistance is equal in all the three phases of secondary winding of zig-zag transformer and the three conductors of the line, the dc current is equally divided in all the three phases.

The conductor of the second transmission line provides return path for the dc current to flow. The saturation of transformer due to dc current can be removed by using zig-zag connected winding at both ends. The fluxes produced by the dc current (Id / 3) flowing through each winding of the core of a zig-zag transformer have equal magnitude and opposite in direction and hence cancel each other. At any instant of time the net dc flux becomes zero. Thus, the dc saturation of the core is removed. A reactor Xd with higher value is used to reduce harmonics in dc current.

In the absence of third order harmonics or its multiple and zero sequence, under normal operating conditions, the ac current flow through each transmission line gets restricted between the zig-zag connected windings and the conductors of the transmission line. The presence of these components may only be able to produce negligible current through the ground due to higher value of Xd.

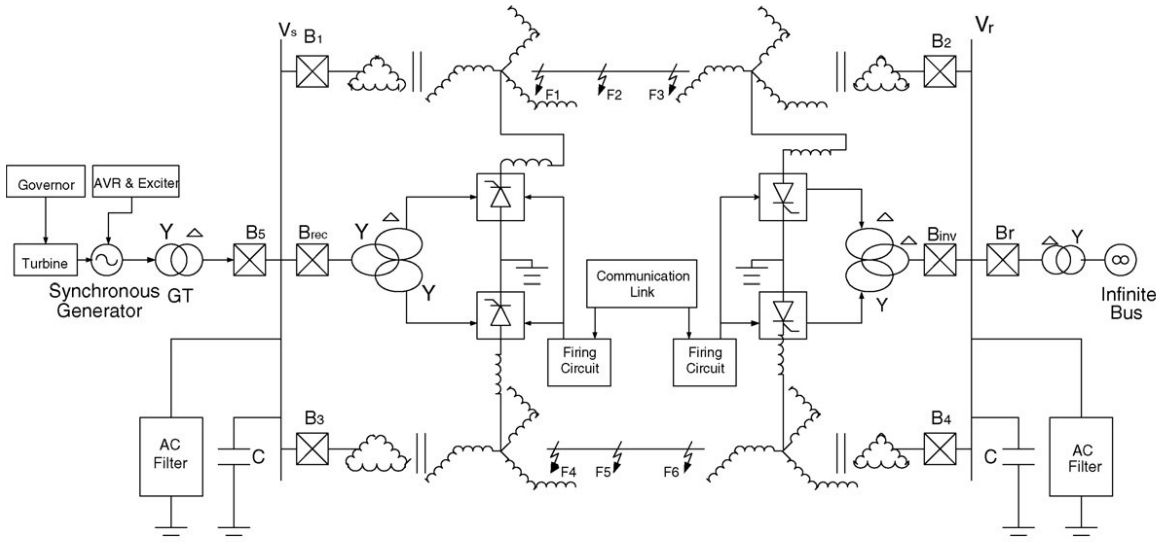



Figure: 1 Basic model for composite ac–dc transmission.

Assuming constant current control of rectifier and constant extinction angle control of inverter, the equivalent circuit of the model considering single ac line under steady-state operating condition is given in Fig. 2.

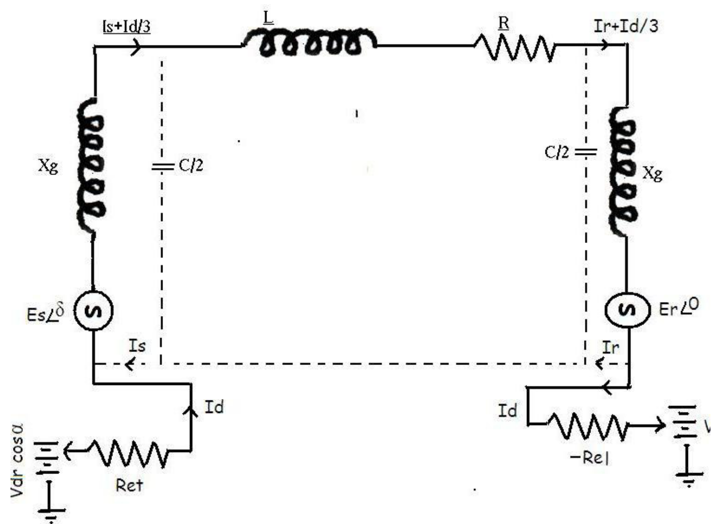



figure 2 Equivalent circuit

The ac current return path is denoted by brisk lines in the figure. The second transmission line acts as the return path for dc current, and each conductor of the line carries (Id / 3) along with the ac current per phase and the maximum values of rectifier and inverter side dc voltages are Vdro and Vdio respectively. The line parameters per phase of each line R, L and C. Rcr and Rci are the commutating resistances, and, $\alpha$ is the firing angle and $\gamma$ is the extinction angles of rectifier and inverter.

## 2.3. Equations:

The chief methodology of solving the equations is by neglecting the resistive drops because of dc currents giving a set of algebraic expressions for ac voltage and current, and also for active and reactive powers in terms of A, B, C, D parameters of each line. These may be written as:

$E_S = AE_R + BI_R$----------------(1)

$I_S = CE_R + DI_R$ ----------------(2)

$P_S + jQ_S = -E_S{*}E_R{*}/B{*} + D{*}E_S^2/B{*}$ ------------(3)

$P_R + jQ_R = E_S{*}E_R/B{*} - A{*}E_R^2/B{*}$ ---------------(4)

If we neglect the resistive drops in the zigzag transformers and the tie lines, the dc current Id, dc power Pdr and Pdi of each rectifier and inverter may be expressed as:

$I_d=[V_{dro} \text{Cos}\alpha - V_{dio} \text{Cos}\, \gamma\, ]/[\, R_{cr} + R_{eq} - R_{ci}\, ]$ -----(5)

$P_{dr} = V_{dr}{*}I_d$ ------------(6)

$P_{di} = V_{di}{*}I_d$ -------------(7)

Reactive powers needed by the converters are:

$Q_{dr} = P_{dr}\, {*}\tan\theta r$ --------(8)

$Q_{di} = P_{di}\, {*}\tan\theta i$ ---------(9)

$\cos\theta r = [\cos\alpha + \cos(\alpha + \mu r)]/2$ ------(10)

$\cos\theta i = [\cos\gamma + \cos(\gamma + \mu i)]/2$ -------(11)

$\mu_i$ is the commutation angles of inverter and $\mu_r$ is the commutation angle of rectifier and the overall active and reactive powers at both the ends are:

$P_{st} = P_S + P_{dr}$ and $P_{rt} = P_R + P_{di}$ -----------(12)

$Q_{st} = Q_S + Q_{dr}$ and $Q_{rt} = Q_R + Q_{di}$ ------- (13)

Transmission loss for each line is:

$P_L = (P_S + P_{dr}) - (P_R + P_{di})$ ------------------(14)

$I_a$ is the rms ac current through the conductor at any part of the line, the rms current per conductor of the line becomes:

$I = [I_a^2 + (I_d/3)^2]^{1/2}$;

Power loss for each line = $P_L \approx 3I^2R$.

The total current I in any of the conductors is offset from zero. Now by setting the net current through the conductor similar to its thermal limit($I_{th}$):

$I_{th} = [I_a^2 + (I_d/3)^2]^{1/2}$ ------------(15)

Let $V_p$ be per phase rms voltage of the initial ac line. Also Let us consider $V_a$ be the per phase voltage of the ac part of simultaneous ac-dc tie line with constant dc voltage $V_d$ composed on it. As the insulators are unchanged, the peak voltage in the two cases must be equal.

If the rated conductor current with respect to its allowable temperature increase is Ith and

$I_a = X * I_{th}$; X ( too less than unity) hence the dc current becomes:

$I_d = 3 \text{ x } (\text{sqrt } (1-x^2) )\ I_{th}$ --------(16)

The total current I in all the conductors are` asymmetrical but the two original zero-crossings in each one cycle in current wave are possessed for $(I_d/3I_a) < 1.414$.

The instantaneous value of voltage of each conductor that is phase to ground voltage can be written as the dc voltage $V_d$ with a composition of sinusoidally varying ac voltages that has rms value $E_{ph}$ and the peak value being:

$E_{max} = V + 1.414\ E_{ph}$

Electric field of the composite AC-DC line also consists of the field produced by the dc line feeding power and also the ac line creating a superimposed effect of electric fields. It can be easily seen that the sudden changes in electric field polarity occurs and it changes its sign twice in a single cycle if $(V_d/E_{ph}) < 1.414$. Therefore, we are free from incurring higher creepage distance for insulator discs used in HVDC lines .

Each conductor has to be insulated for the maximum $E_{max}$ but the fact is line to line voltage has no component of dc voltages and $E_{LL(max)} = 2.45\ E_{ph}$. Therefore, we come to the conclusion that conductor to conductor separated distance is found out only by ac voltage of the line in lieu of the total superimposed one.

Assuming $V_d/E_{ph} = k$

$P_{dc}/P_{ac} = (V_d * I_d)/(3 * E_{ph} * I_a * \cos\theta) = (k * \mathrm{sqrt}(1-x^2))/(x * \cos\theta\ )$ ------------(17)

Total power

$P_t = P_{dc} + P_{ac} = (1 + [k * \mathrm{sqrt}\ (1-x^2)]/(x * \cos\theta)) * P_{ac}$ ------------(18)

Detailed analysis of the filter and instrumentation networking which are required for the proposed scheme and also short current ac design for protective scheme is out the scope of present work, but preliminary analysis qualitatively presented below says that generally used techniques in HVDC/ac composite system can be adopted solely for this purpose.

Different values of ac filters and dc filters are used in HVDC system and these may be connected to the delta side of the transformer and zigzag neutral respectively to filter out higher harmonics that is (n*p+1)th order and the (n*p)th order from dc and ac supplies. Moreover ,filters also may be omitted for very low values of $V_d$ and $I_d$. In the neutral terminals of zigzag transformer winding dc current and dc voltages can be found out by incorporating common methods that are used in HVDC system. Conventional cvts or capacitive voltage transformer as used in EHV ac lines to measure stepped down ac component of transmission line voltage. The composite ac-dc voltage in the transmission line does not trouble the working of cvts. Linear couplers that has high air-gap core may be used for measuring ac component of line current as the dc component of line current cannot saturate high air-gap cores.

# CHAPTER 3

# PROPOSED SIMULINK MODELS

## III. Simulink Models:

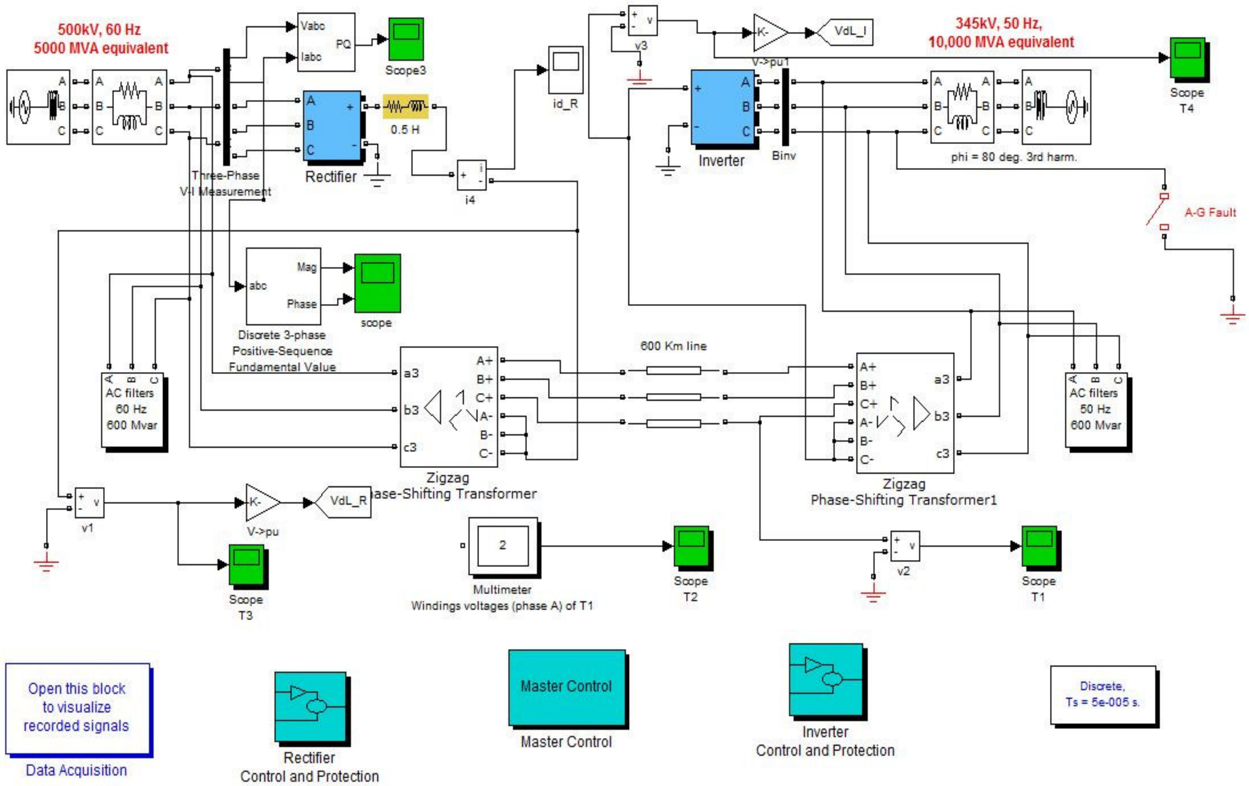



*Fig. 3: Simulink Model (single line circuit) using Simultaneous AC-DC Transmission*

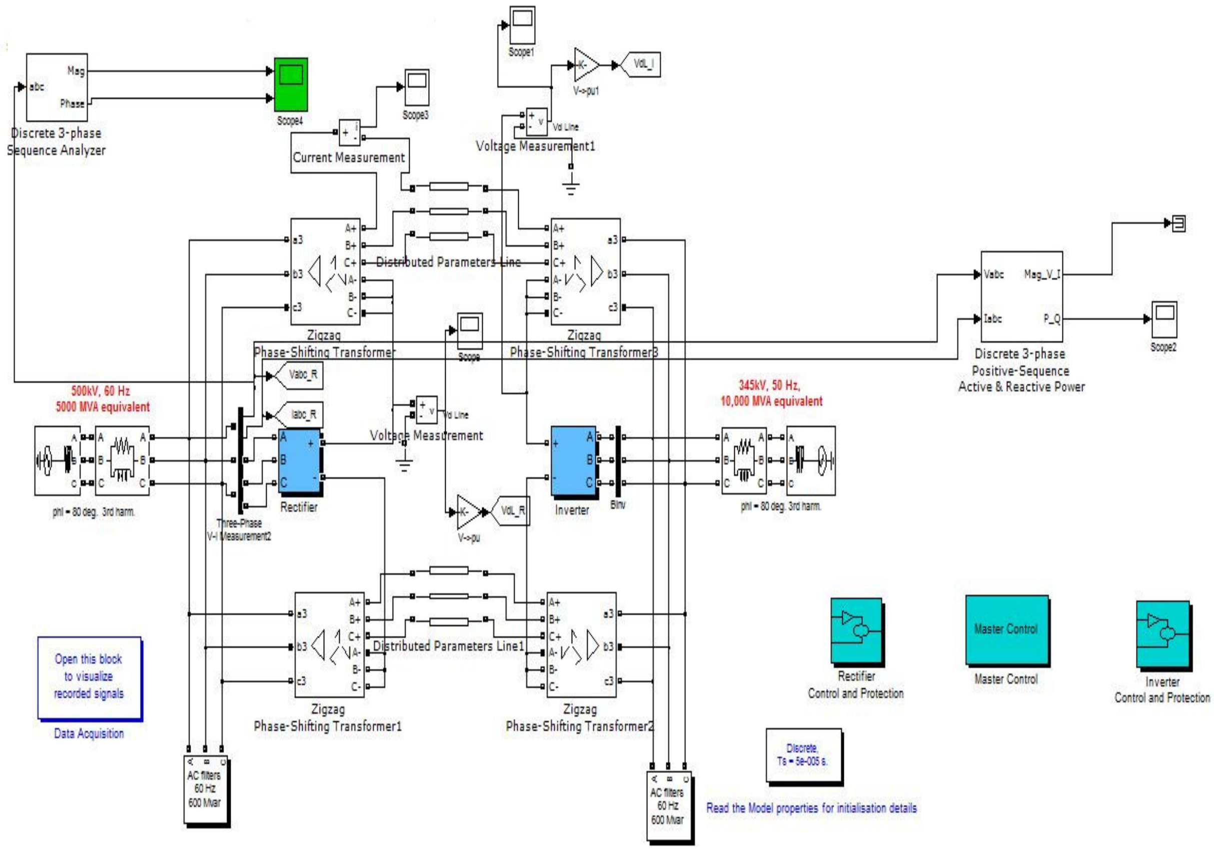


*Fig. 4: Simulink Model (double line circuit) using Simultaneous AC-DC Transmission*

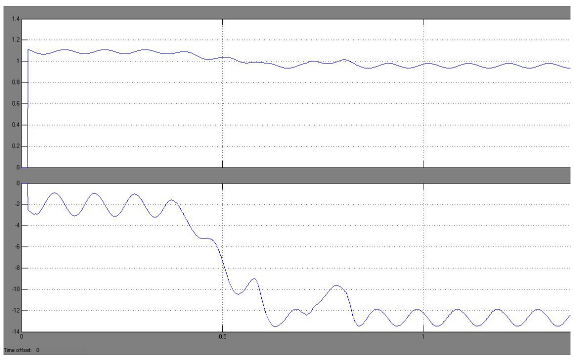
The study is based on the comparison between the response under no fault and fault conditions for combined EHV and HVDC transmission (double circuit line) through simulink in MATLAB. A comparision between between the sending end and receiving end voltages and sending end and receiving end current for the two cases have been done.the active and reactive power changes during fault and no fault conditions are also observed. Initially we have started with single line ac-dc transmission with one sending end station that is a rectifier station and one receiving end station that is an inverter station. It caters to a small amount of power transfer and voltage and current profiles are studied with fault and without fault. This system is less reliable with more transient response time. Then we shifted towards a double line transmission with 2 sending end stations and 2 receiving end stations making a more reliable and stronger system capable of overcoming any adversities or shortcomings. It is actually designed for a larger chunk of load transfer . it also guarantess continuous supply if one station is interrupted due to internal or external faults. The voltage, current and power profiles are studied during fault and without fault and it is found to have better transient response than single circuit.

# CHAPTER 4

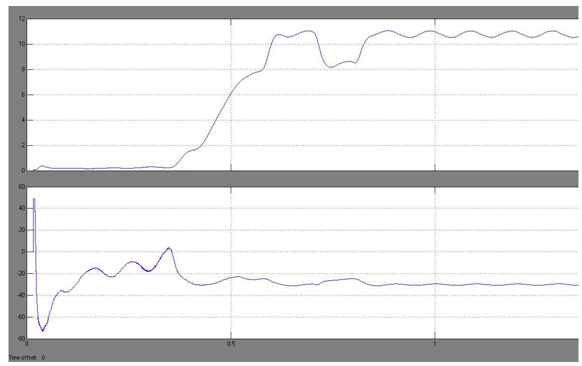
# RESULTS

## IV. RESULTS:

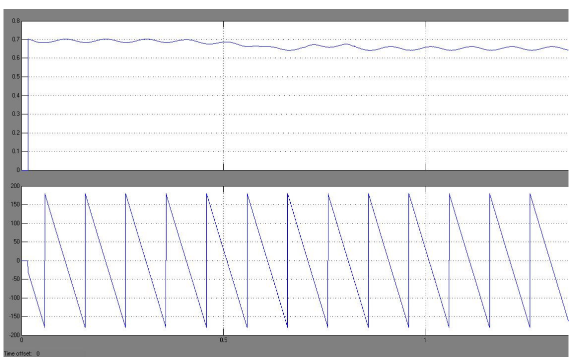
### 4.1. Normal Response Without Fault:



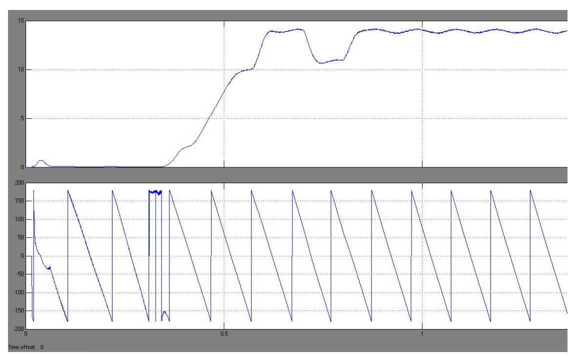
a) **Sending end voltage mag. and phase**



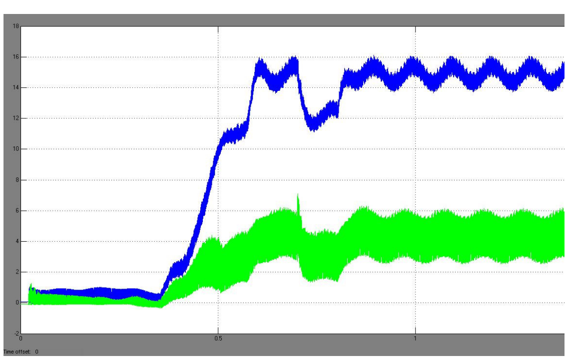
b) **Sending end current mag. and phase**



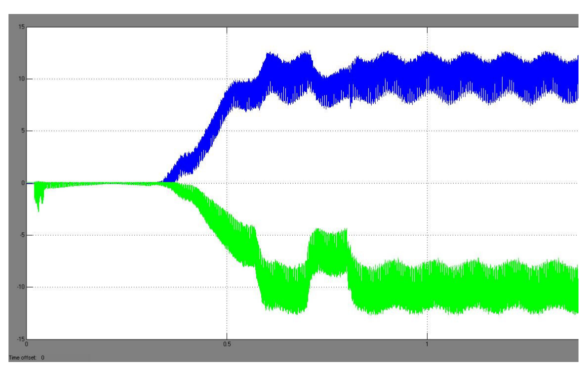
c) **Receiving end voltage mag. and phase**



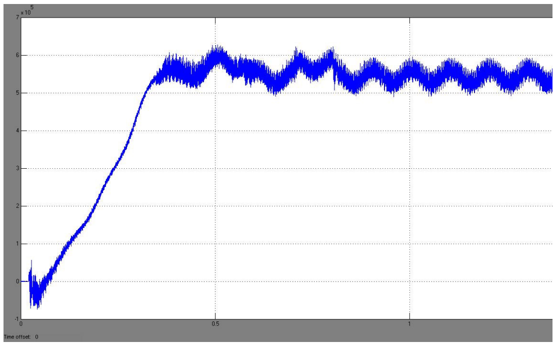
d) **Receiving end current mag. and phase**



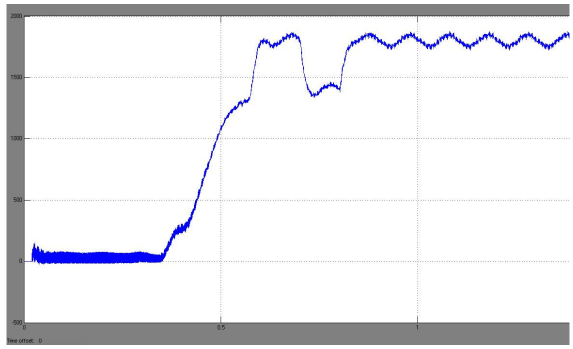
e) **P,Q sending end side**



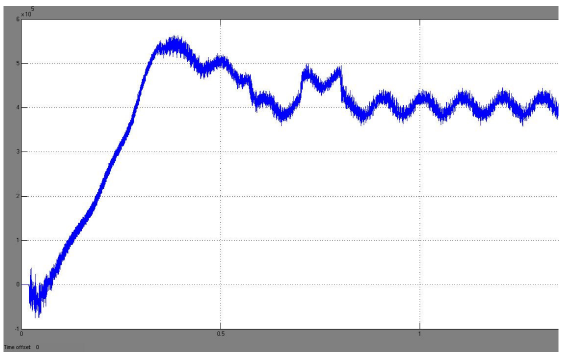
f) **P,Q receiving end side**



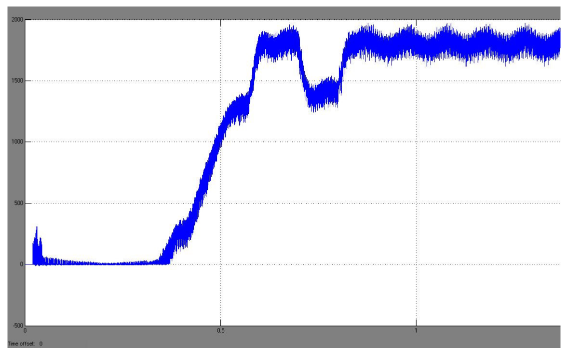
**g) Rectifier dc voltage**



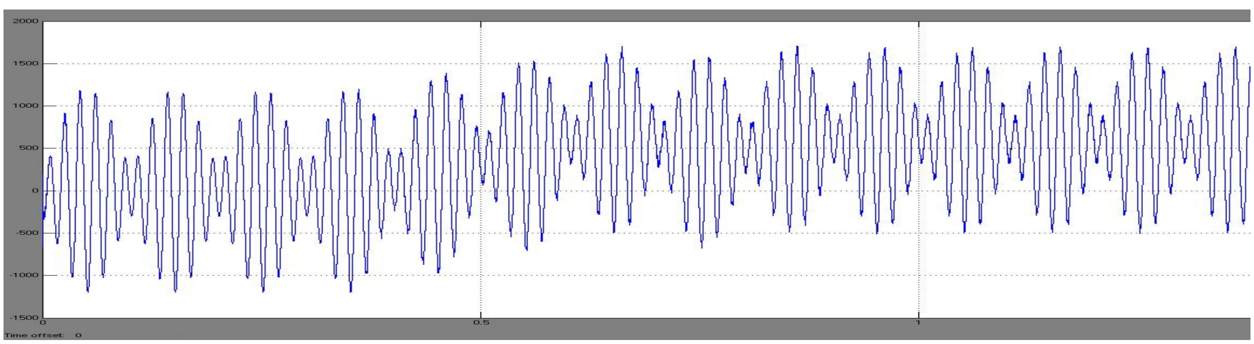
**h) Rectifier dc current**



**i) Inverter dc voltage**

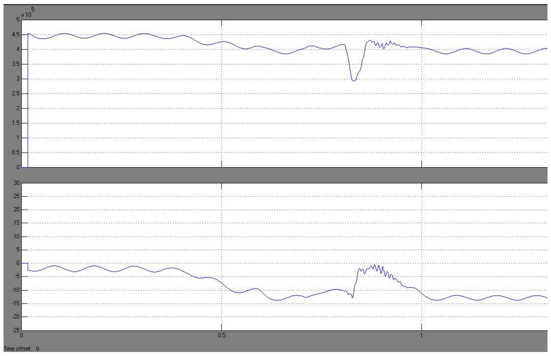


**j) Inverter dc current**

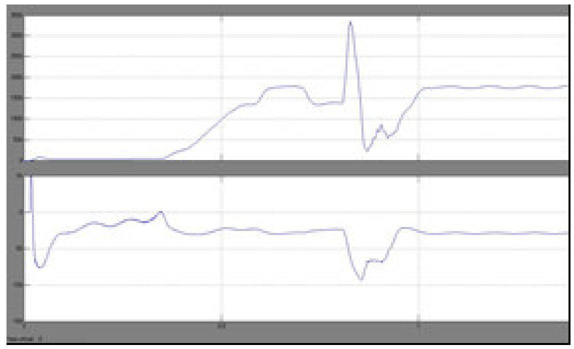


**k) Total current under no fault**

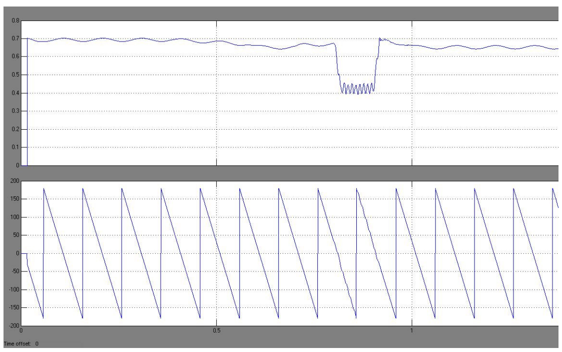
## 4.2. Response Under Fault:



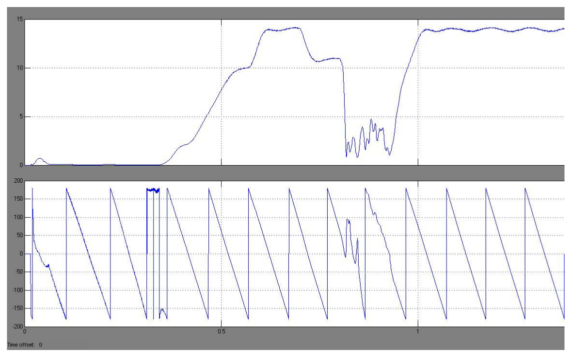
a) Sending end voltage mag. and phase



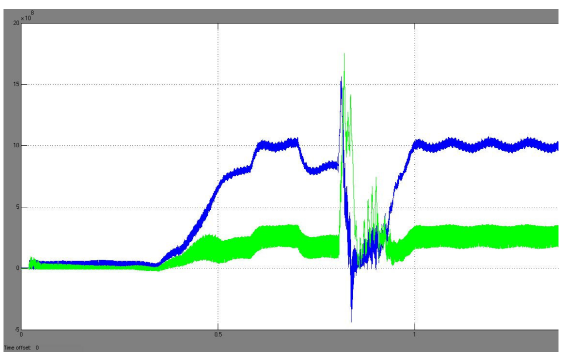
b) Sending end current mag. and phase



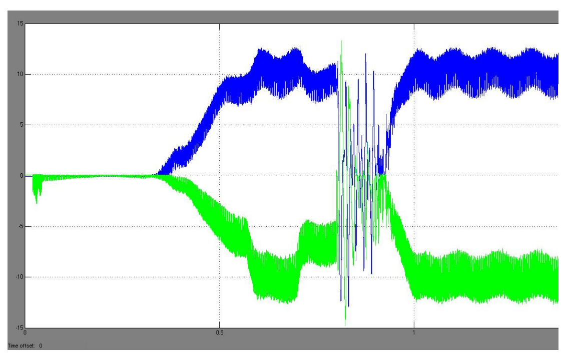
c) Receiving end voltage mag. and phase



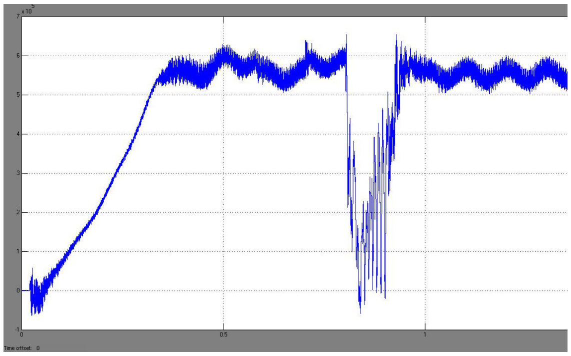
d) Receiving end current mag. and phase

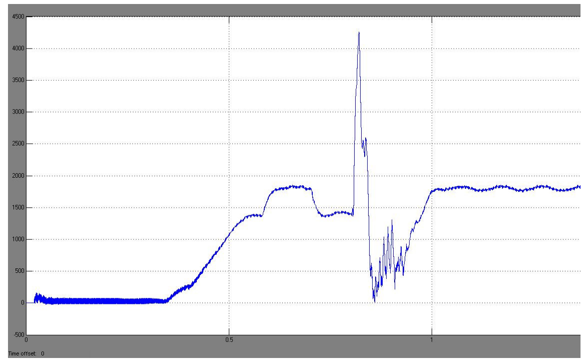


e) P,Q sending end side



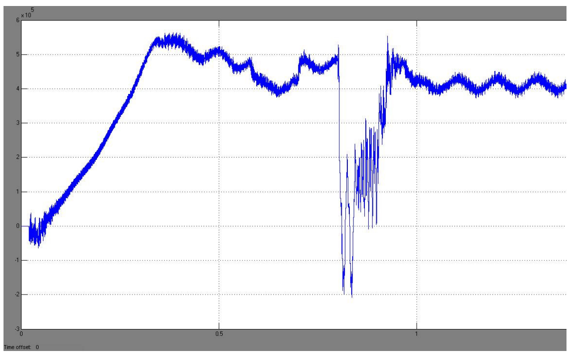
f) P,Q receiving end side

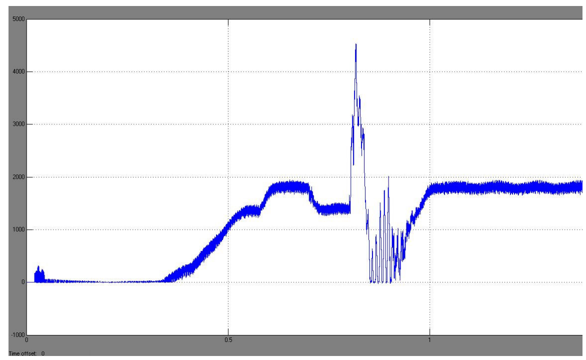




**g) Rectifier dc voltage**

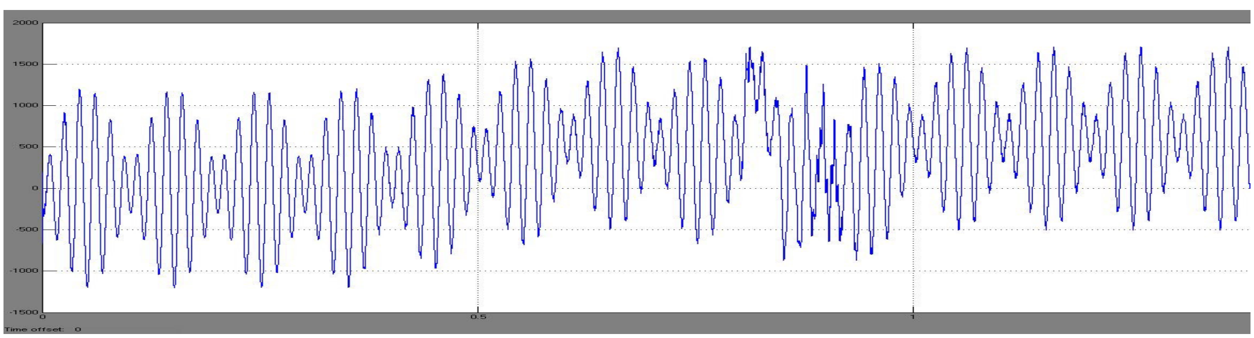
**h) Rectifier dc current**





**i) Inverter dc voltage**

**j) Inverter dc current**




**k) Total current under no fault**

Under fault conditions the sending end voltage and receiving end voltage suddenly dips with recovering of original waveform after fault is cleared. The sending and receiving end currents rises to a certain spike and then recovers gradually. In general the voltage of across the rectifier and inverter dips on the occurrence of fault whereas the current level spikes under fault conditions. The above results are obtained by using a single line to ground fault in the distributed parameters for the single circuit line model.

The results remain almost similar under dc fault. Under fault conditions the reactive power requirement increases as can be inferred from the graph. As the reactive power is utilized in the circuit hence the reactive power at the receiving end side is lowered to a negative value. The single line circuit model uses ground as return path. Hence use of unipolar dc link for simultaneous ac-dc transmission can pose threats to the equipments located nearby in the ground since using ground as return path can corrode the metallic material if it is in its path.

Another thing is that the sluggishness in the system is removed, if we consider an EHV line and on occurrence of a fault the transient response of the system for example the voltage profile or the current or the sudden surge in the reactive power requirement has inherent sluggishness, the system requires a long time to recover. But by using the simultaneous ac-dc model the transient response is increased and hence the transient stability.

The stability is further enhanced because of quicker current control mechanism of HVDC blocks that is the rectifier and inverter blocks. In the control mechanism there is a master control and separately there is inverter and rectifier protection which works on VDCOL control procedures. Whenever the voltage dips on occurrence of a fault the current is restricted so the fault current is also decreased and the most significant thing is that it has very small time constant that is it works very fast.

# CHAPTER 5

# CONCLUSION

## V. CONCLUSION:

The EHV ac lines, because of inherent transient stability problem cannot be loaded to their maximum thermal limit. With the present simultaneous ac-dc transmission it is feasible to load these tie lines close to thermal limits specified in the data sheets. Here the conductors are carrying superimposed dc current with ac current. The added dc power flow is flawless and is not the cause of any transient instability. This thesis shows the possiblity of converting a dual circuit ac line into simultaneous ac-dc power transmission block to improve power transfer as well as to achieve reliability in the power transfer. Simulation studies are being made for the co-ordinated control and also individually the control of ac and dc power transmitted through the lines. There is no physical alteration in insulator strings, towers and arresters of the original line .There is substantial gain in the loading capability of the line .There is a master controller which controls the overall current that is flowing in the lines so in case of fault also the current is limited and stability is enhanced .

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